

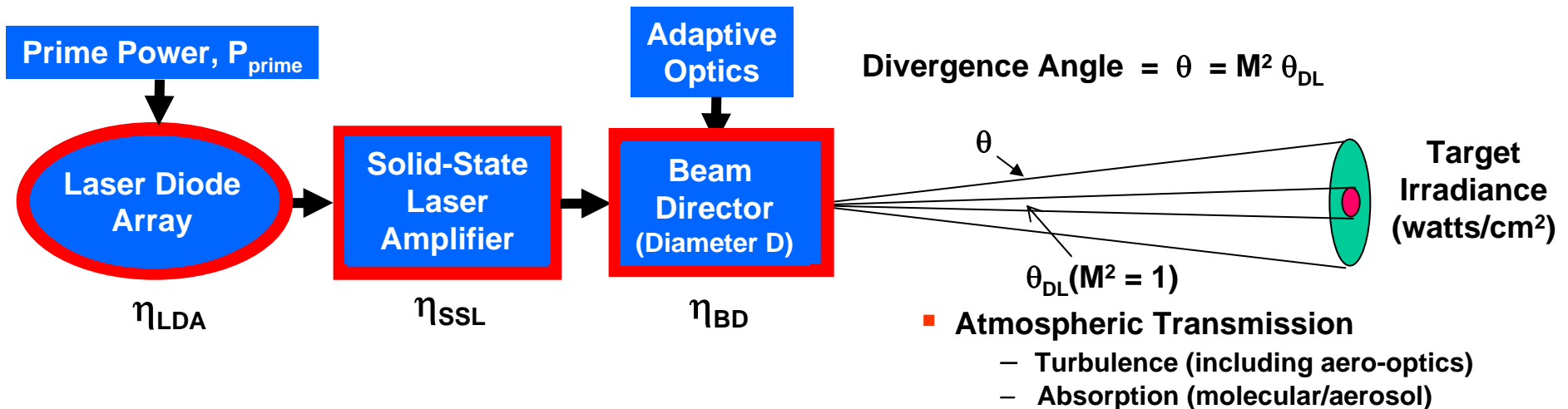
Electronically-Steerable, Coherent Laser Arrays

REALLY Small, Lightweight, High Power Lasers for DoD Applications



MTO Symposium
Joseph Mangano, PM
March 7, 2007

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■ Power Delivery Efficiency $\sim \frac{\eta_{\text{LDA}} \eta_{\text{SSL}} \eta_{\text{BD}}}{M^4}$

■ Challenges

- Power Scaling
- Efficiency
- Beam Quality
- Size and Weight
- Lifetime/Reliability
- Electronically-steered, Conformal, Adaptive, Optical Phased Arrays

Technologies:

- Electronically-Steered, Optical Phased Arrays driven by:
 - Fiber Laser Amplifiers (APPLE)
- or directly by:
 - Coherent Laser Diode Arrays (COCHISE)

Challenge: Electronically-Steered 100 kW Laser System at 2 kg per kilowatt



APPLE Laser Beam Directors

Adaptive Photonic Phase-Locked Elements



APPLE Beam Director Technology can provide:

- All-Electronic Beam Steering with 45° Field-of-Regard
- Power and Aperture Size Scaling through Coherent Beam Combining of Multiple Sub-apertures (2.5 - 5 cm dimension)
- Conformal to Most Military Platforms
 - replaces aerodynamically-challenged turret-mounted beam directors
- Near-Diffraction-Limited Beam Quality, Corrected for:
 - atmospheric turbulence — $r_o \sim 5 \text{ mm} / BW_{\text{atm}} \sim 1 \text{ kHz}$
 - aero-optic effects — $r_o \sim 5 \text{ cm} / BW_{\text{atm}} \sim 10 \text{ kHz}$

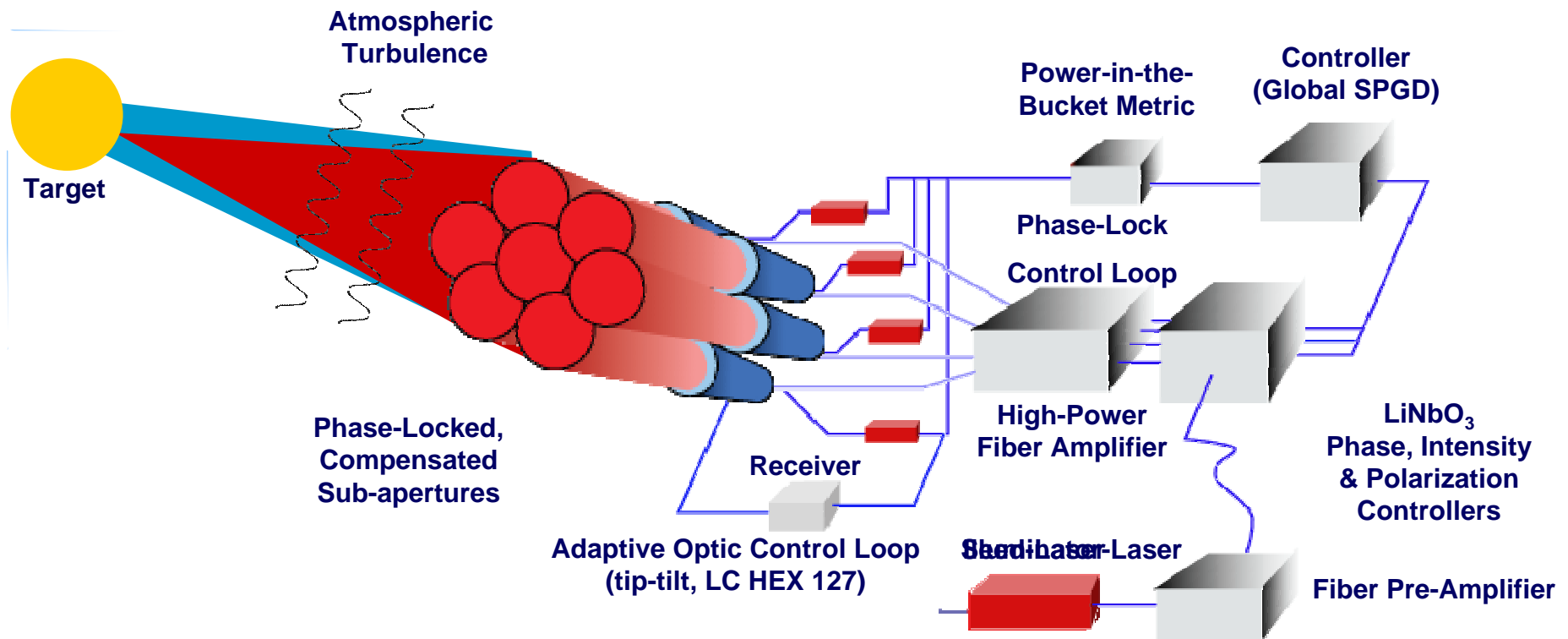
Fast, Electronically-Steered, Optical Phased Array
***adaptable* to essentially all DoD Laser Applications**

**Multiple, Conformal, Electronically-Steered Subapertures
Independently Targeted or Coherently Combined into a Single Beam**



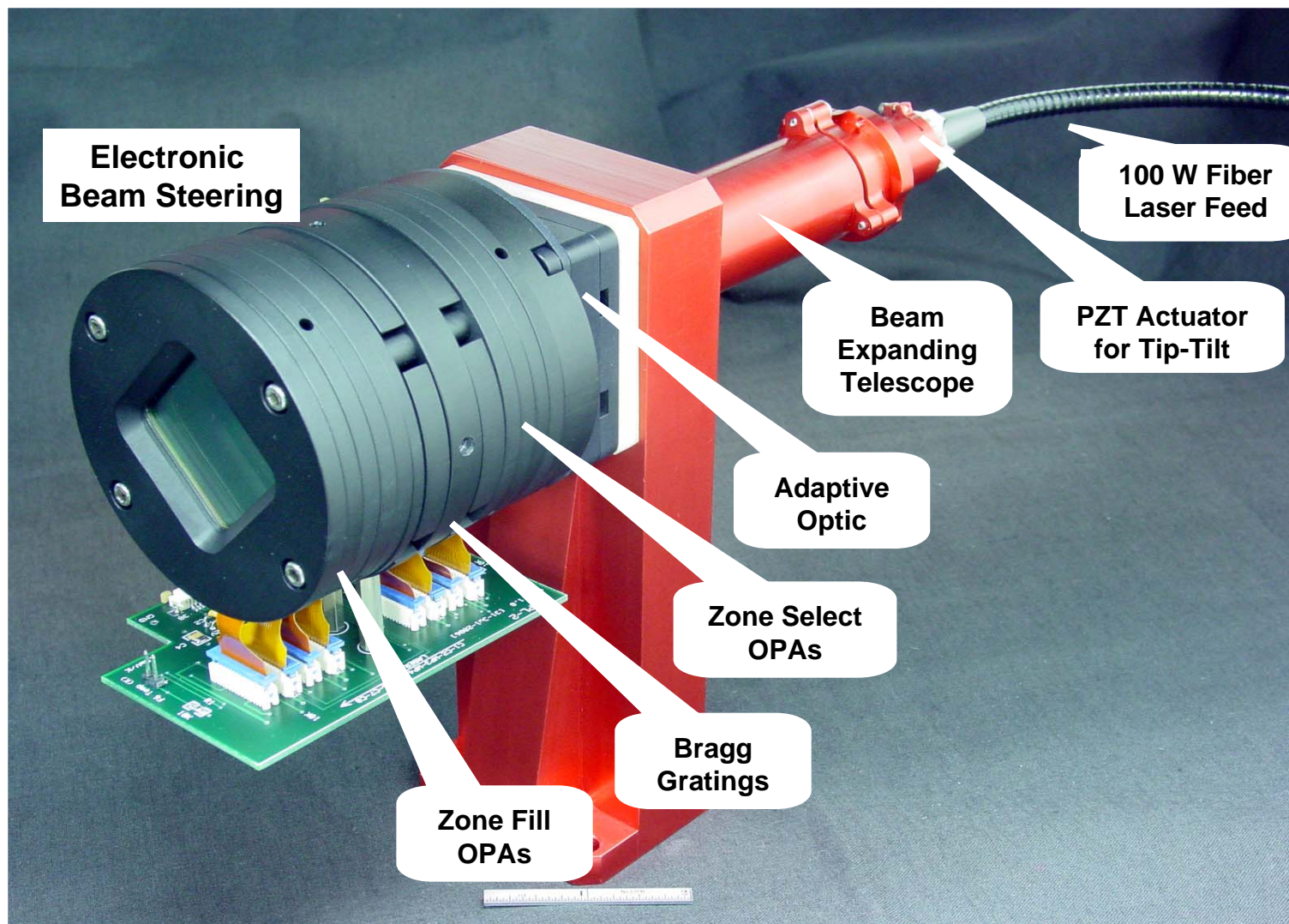


APPLE Concept





Assembled APPLE Subaperture



Challenge: Coherent Array of APPLE Subapertures with Fast Adaptive Optics

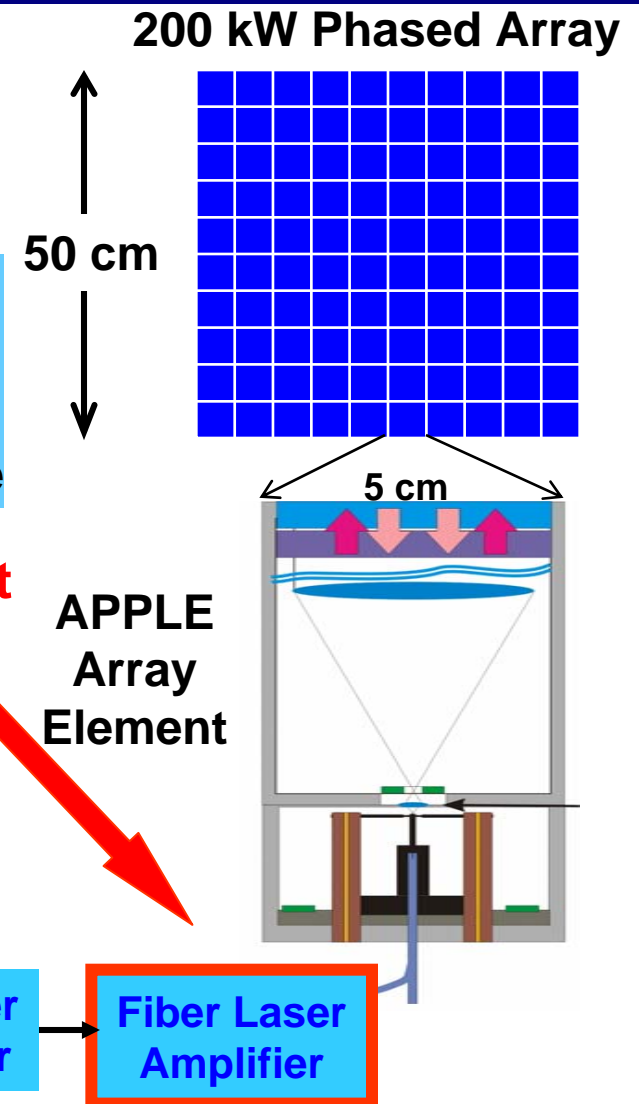


Weapon Concepts Require **Single-Mode, Narrowline**, Kilowatt-Class Fiber Lasers



- 100 Coherently-Combined Apertures (10 x 10 Array)
- Need High Power Fiber Laser Amplifiers
 - 2 kW
 - Single Transverse Mode
 - Single Polarization
 - $< \lambda/20$ Phase Noise – No SBS/SRS - Narrowline
- These 2 kW Fiber Laser Amplifiers do not exist
 - 200 watts Commercially Available

Challenge: Scale these Fiber Amplifiers to 2 kW and Beyond





Coherent, High Power Laser Diode Arrays



■ Why Coherent Diode Arrays?

- Electrical Efficiency
 - Thin Disk Lasers (HELLADS) 15%
 - Fiber Lasers 25-30%
 - **Coherent Laser Diode Arrays 30-50%**



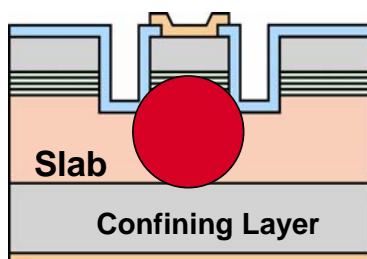
Increasing
Risk

■ Three Approaches:

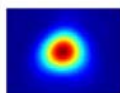
- Talbot Cavity – Spatially-Coupled Oscillators in Supermode
- Phase-Locked Loops driven from a common seed beam
- Coherent Combining with SPGD Algorithm as in APPLE

Challenge: Coherently Combine Kilowatt Laser Diode Arrays

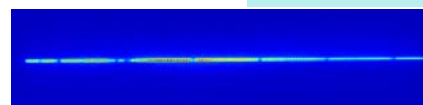
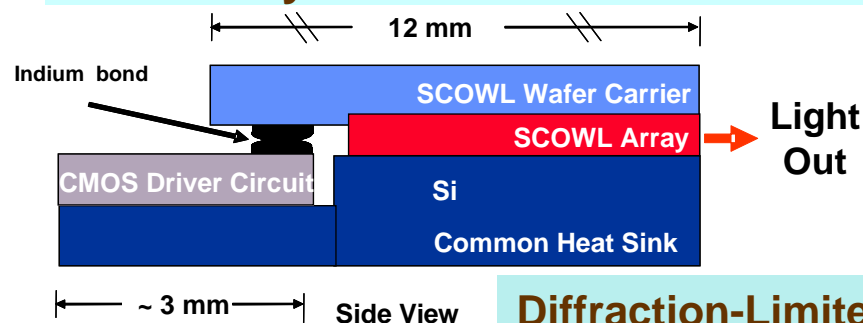
Slab-Coupled Optical Waveguide Laser (SCOWL)



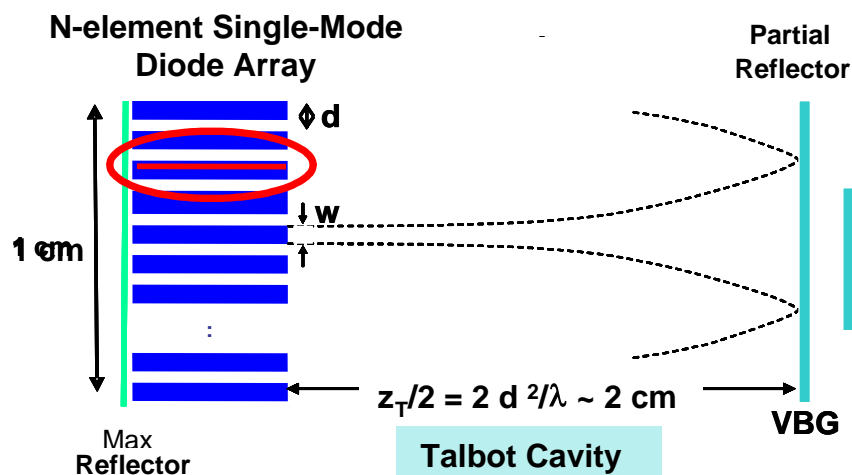
- 1 watt
- Single Mode
- **Ultra-low Noise**



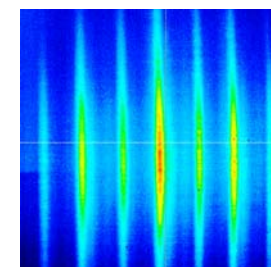
Individually drive Each Emitter in the Bar



Talbot Cavity - Laser Diode Phased Array



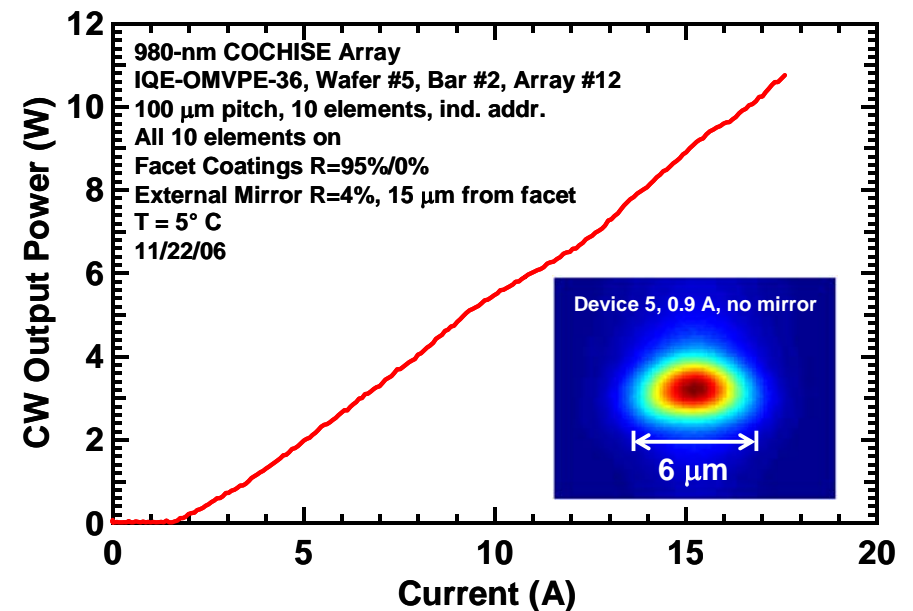
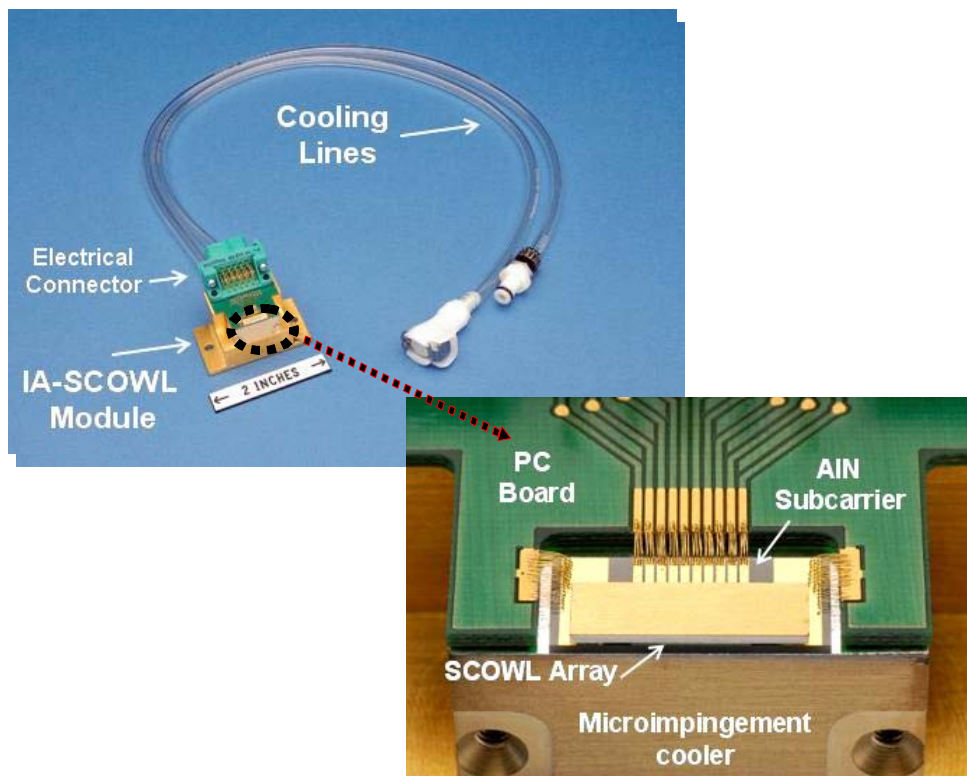
Coherent Output Beam



Remove Multi-Mode, Unphaseable Rogue Emitters in 10s of nsec

Drive each Emitter in SCOWL Bar Independently

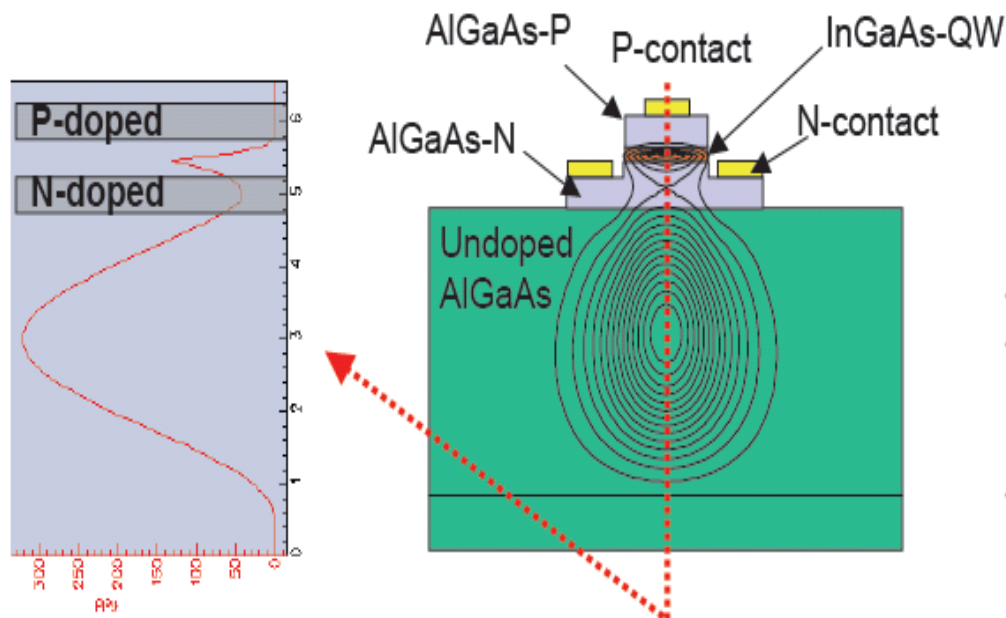
Independent Drivers for Each Emitter in a 10-Emitter Bar



Challenge: CMOS Drivers Conformally Coupled Directly to the Diode Bar for Current Sharing and Phase Control

Vertically-Coupled Large Area (VECLA) Laser

Challenge: 10 watt, low noise, single-mode emitters at 50% Efficiency



Low Optical Loss

- High power
- High efficiency

Low confinement

- Stable spatial mode

Design Features

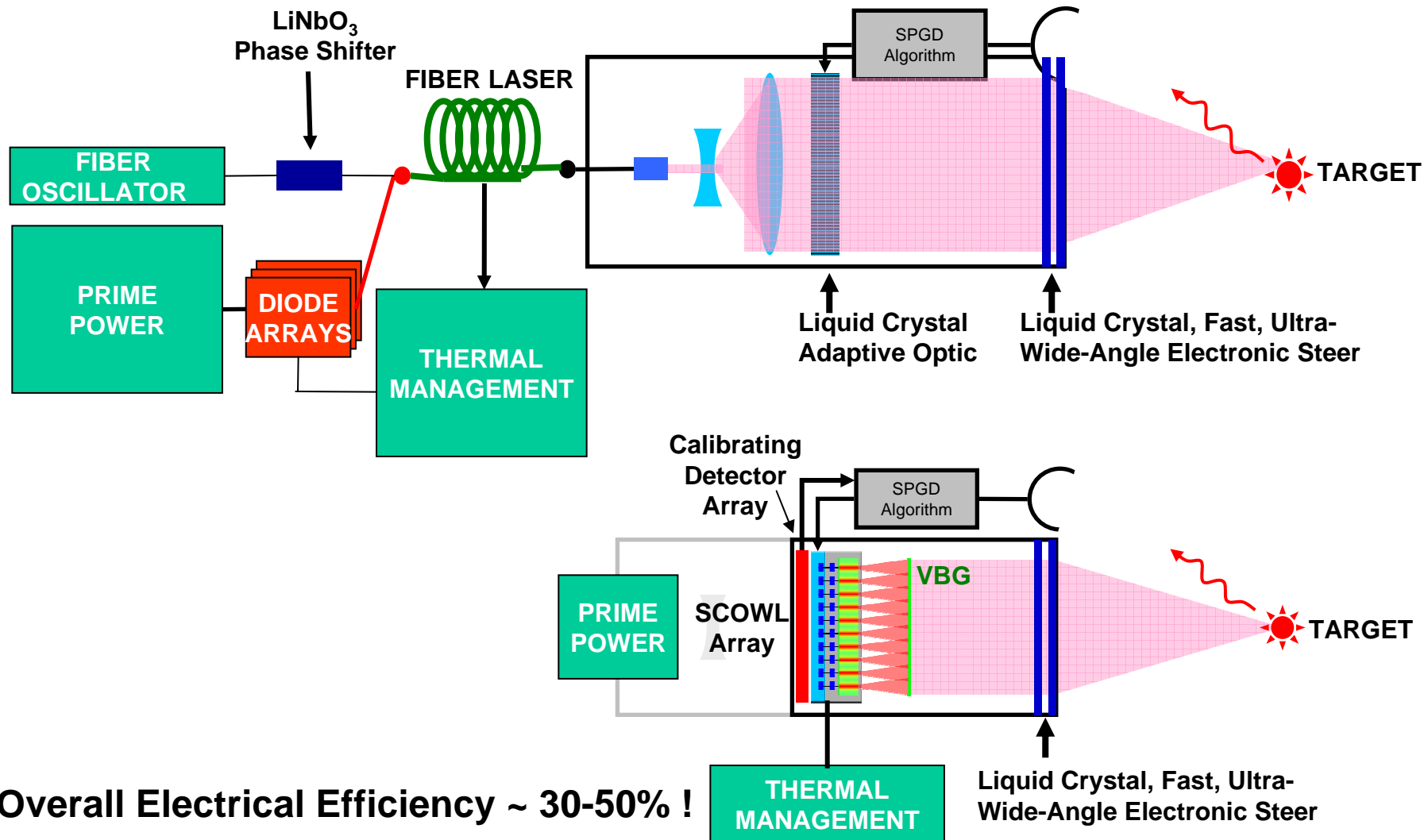
- Low modal overlap to doped layers (<0.02)
- Highly doped cladding layers ($\sim 10^{18} \text{ cm}^{-3}$)
- Thin top cladding layer ($\sim 0.05 \mu\text{m}$)
- Large optical mode ($\sim 4 \times 15 \mu\text{m}^2$)

Performance

- Very low optical internal loss ($<0.2 \text{ cm}^{-1}$)
- Very low electrical resistance, but not too low
- Very low thermal resistance ($\sim 2^\circ\text{C/watt-mm}$)



APPLE Sub-aperture driven by a Coherent Laser Diode Array



Overall Electrical Efficiency ~ 30-50% !

Potential: 100 kW Laser Systems at 2 kilograms per kilowatt!



Additional Challenges and Areas of Interest



■ **Laser Diode Technology – for pumping Thin Disk Lasers**

- **Increase SHEDS Diode Bar Power to ≥ 100 watts/bar-cm**
 - Efficiency $\geq 70\%$
 - Lifetime > 1000 hours
 - 1 cm bar with 1.5 mm pitch
 - Wavelength $\sim 808\text{nm}$ (Nd:YLF or Nd:ceramic YAG Pump)
- Thermal Resistance from Junction to Heat Sink is the limiting factor

■ **Fiber Laser Technology – 100 kW**

- **Explore Ultimate Fiber Amplifier Array Scaling Limits**
 - Single-Mode ($M^2 < 1.5$)
 - Single-Polarization
- Pump Diode Brightness is the limiting factor



Some of My Current Program Responsibilities



■ Existing Programs:

- | | | | |
|----------------|---|-----------------|-----------|
| – APPLE | – Conformal Laser Beam Director | } Briefed Today | } Posters |
| – COCHISE | – Coherent Combining of Laser Diodes | | |
| ADHELs | Single-Mode Laser Diode Development
Laser Diode Reliability and Lifetime | | |
| – SHEDS | – Laser Diode Efficiency | | |
| – Ultrabeam | – X-ray Lasers | | |
| – Nanowriter | – E-Beam, Direct-Write, Maskless Lithography Tool | | |
| – IM-VAC (DSO) | – Compact CT Imaging Technology for Battlefield Use | | |

....so see Dr. John Zolper, Director of MTO now!!!
Get Recruited as a New MTO Program Manager



Back ups

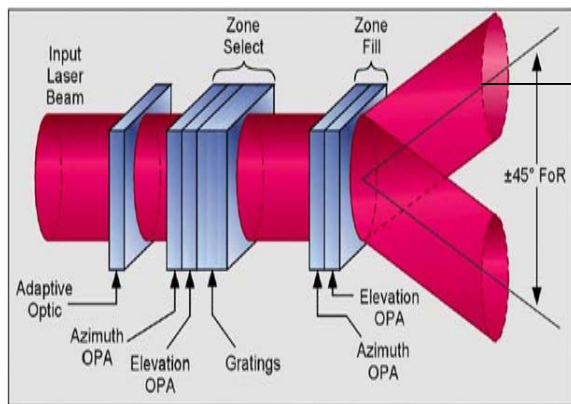




APPLET Components



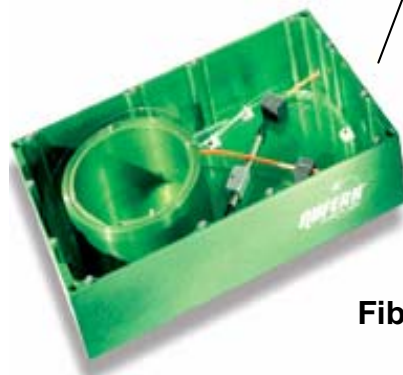
Fast Beam Steering Element



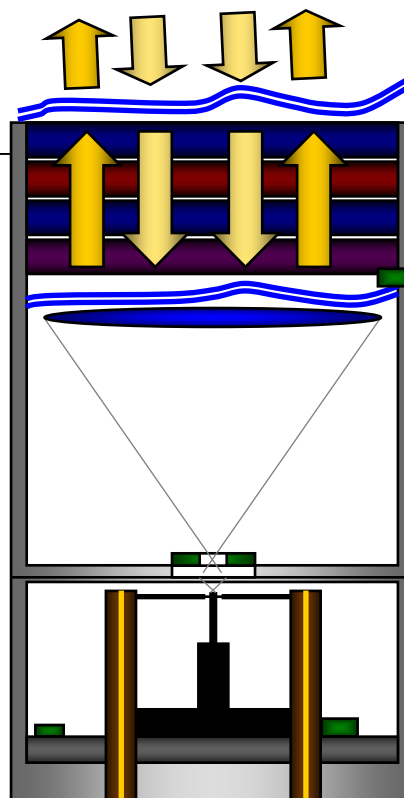
**SPGD Algorithm
implemented on FPGA**

LiNO₃ Electric Field Controller

- Intensity
- Phase
- Polarization

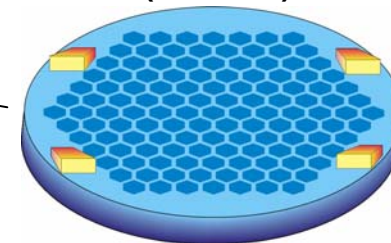


Fiber Laser Amplifier

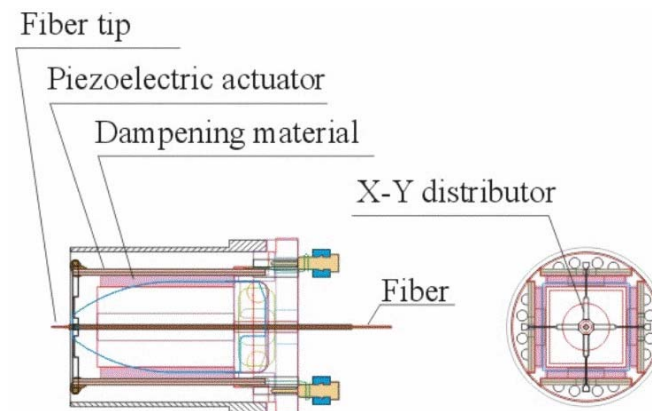


APPLET

Adaptive Optics Element (HEX 127)



**Challenge:
– 10x Faster Adaptive
Optic Elements**

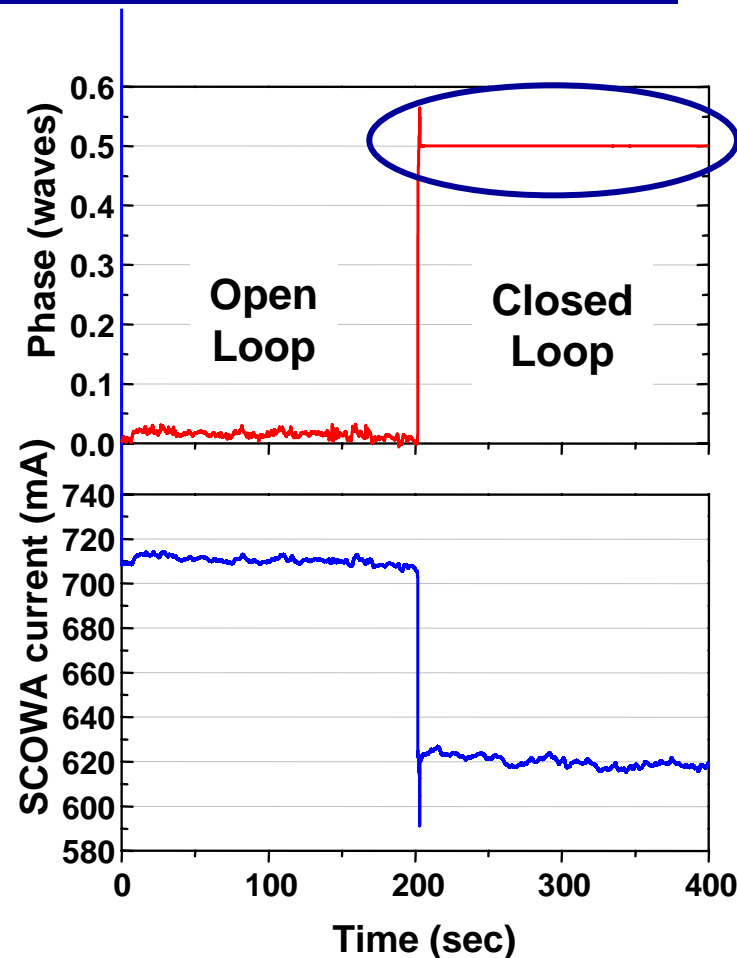
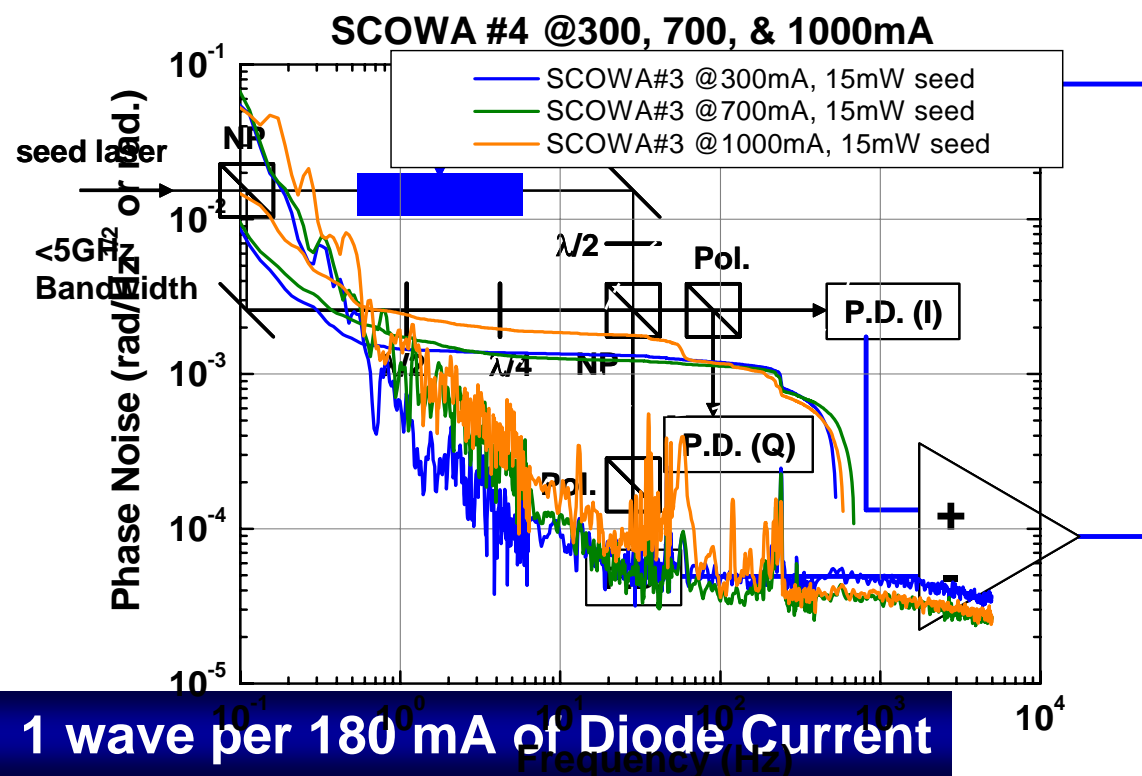


Tip/Tilt Compensator

Phase-Locked Loop around a SCOWL Amplifier

Mach Zehnder Interferometer measures Phase for Feedback Control

SCOWA Phase Noise



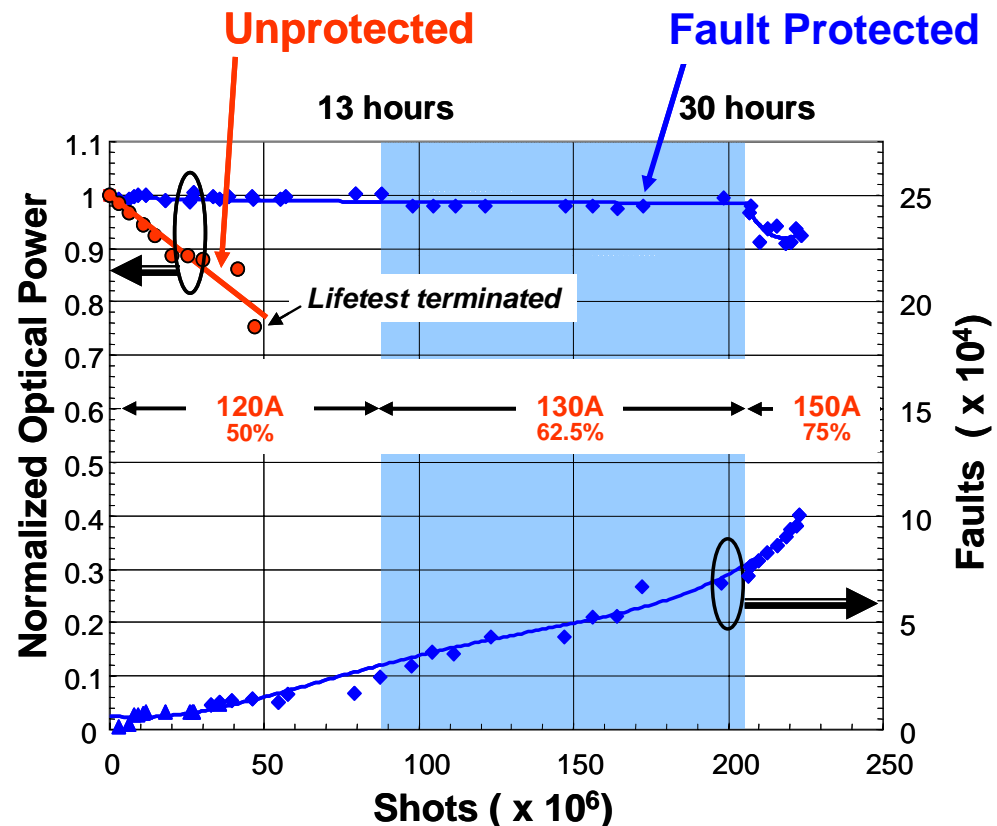
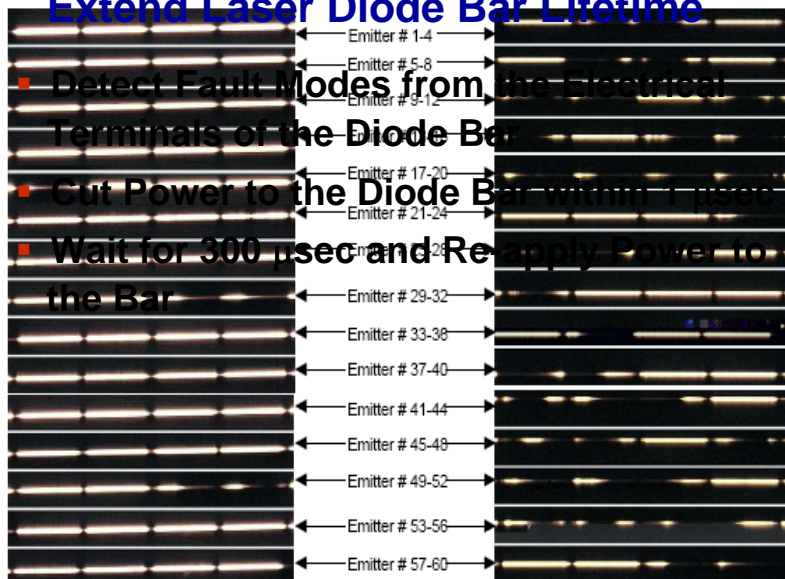
Challenge: Coherent Array of High Power Laser Diode Amplifiers at 2 kW

Protected

Unprotected

Extend Laser Diode Bar Lifetime

- Detect Fault Modes from the Electrical Terminals of the Diode Bar
- Cut Power to the Diode Bar within 1 μ sec
- Wait for 300 μ sec and Re-apply Power to the Bar



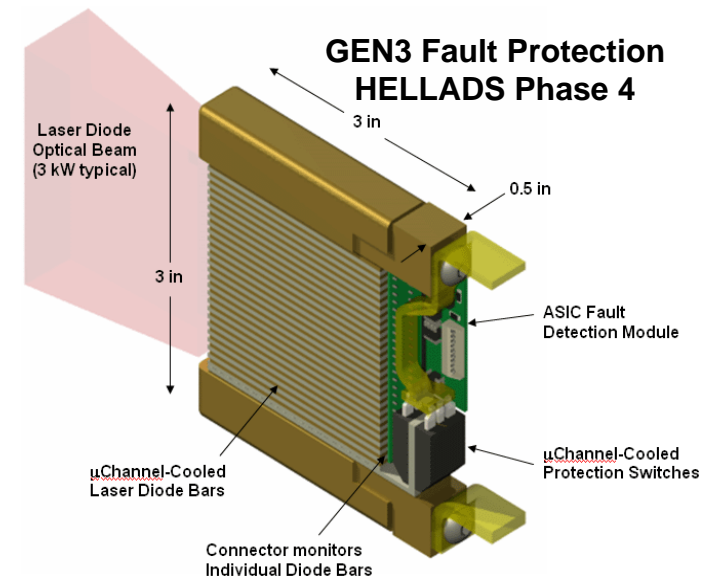
Fault Mode Frequency increases with Diode Bar Current

**Eliminating Rogue Modes extends Diode Bar Lifetime by >10x
No Impact on Average Power or Efficiency**

✓ **Efficiency** = = **50%** ⇒ **70% SHEDS**

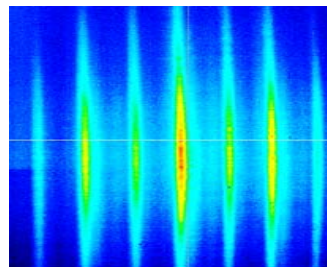
Cochise Program Goals

- **Lifetime** = **10 – 100 hours** ⇒ **>1000 hrs** for HELLADS and SHEDS
- +**
- **High Power per Bar** = **85 watts/bar** for HELLADS then **>100 watts/bar**
- +**
- **Diode Beam Quality** = **35x Diffraction Limit** ⇒ **< 1.4x Diffraction Limit**
- +**
- **Coherent Combination** = **No** ⇒ **Yes**



**Unique COCHISE Diode Protection
Extends Diode Lifetime by >10x**

**Brightness
and
Coherence**





Cochise will increase Power and Safe Operating Temperature of Laser Diode Bars

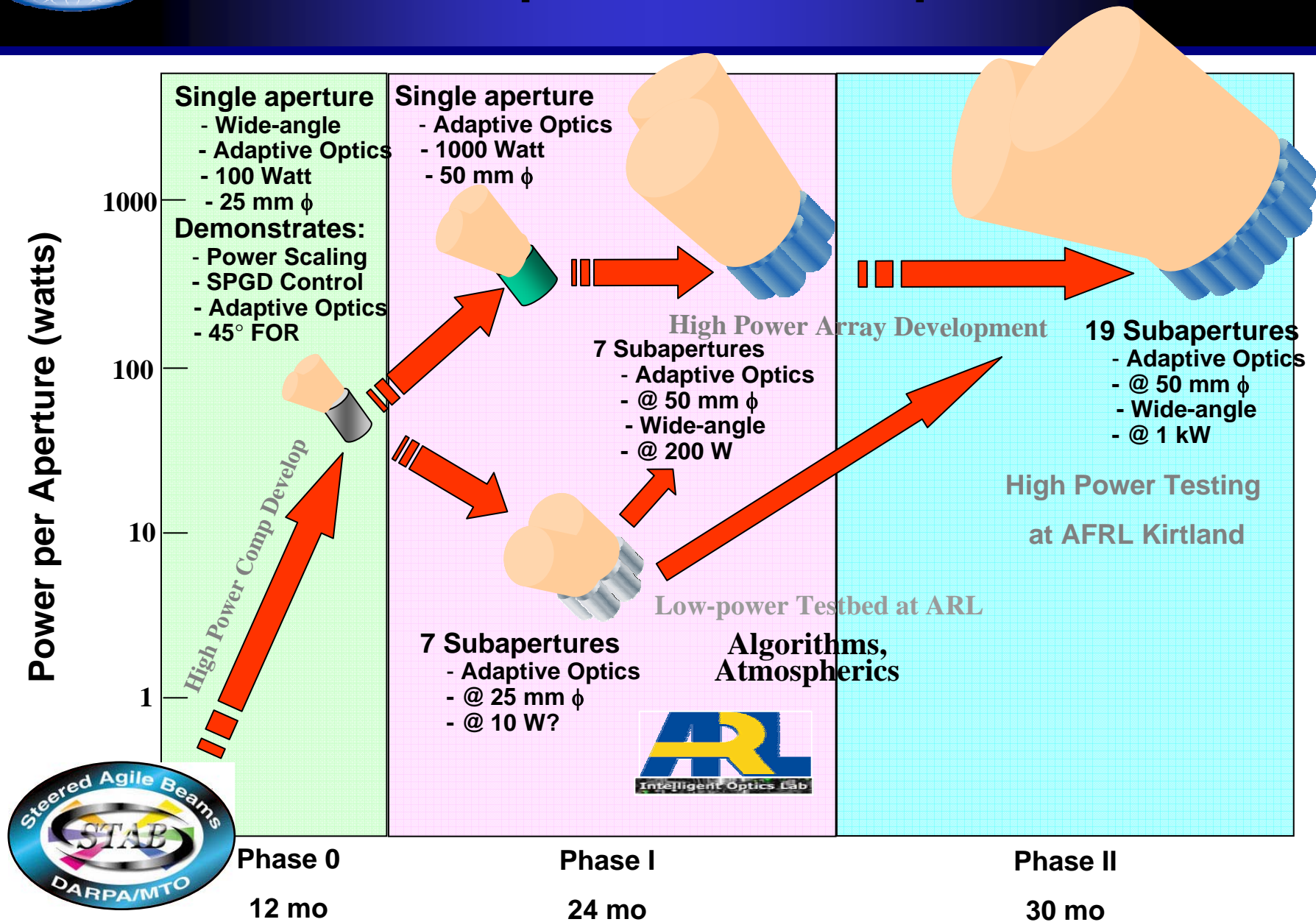


- In Year 2, COCHISE will Extend HELLADS Diode Bar Lifetime at Higher:
 - Diode Bar Power 85 Watts \Rightarrow >100 Watts
 - Inlet Coolant Temperatures 35°C \Rightarrow >50°C
- Reduce Laser Weapon System Size, Weight, and Cost
 - Impacts:
 - HELLADS Phase 4
 - DARPA Fiber Laser Program
 - All DoD Diode-Pumped Solid State Laser Programs

**Challenge: 200 watts/bar-cm by Combining Diode Protection with
Improved Bar Cooling Technology**



Proposed Roadmap



Solid-State Laser Amplifiers

■ Challenges

- Scalability
- Efficiency
- Beam Quality/Coherence
- Size, Weight, Power

■ Programs

- HELLADS (TTO)
- HPFL (TTO)
- ADHELDS/COCHISE

■ Technologies

- Thin Disks
- Fiber
- Coherent Diode Arrays

Beam Directors

■ Challenges

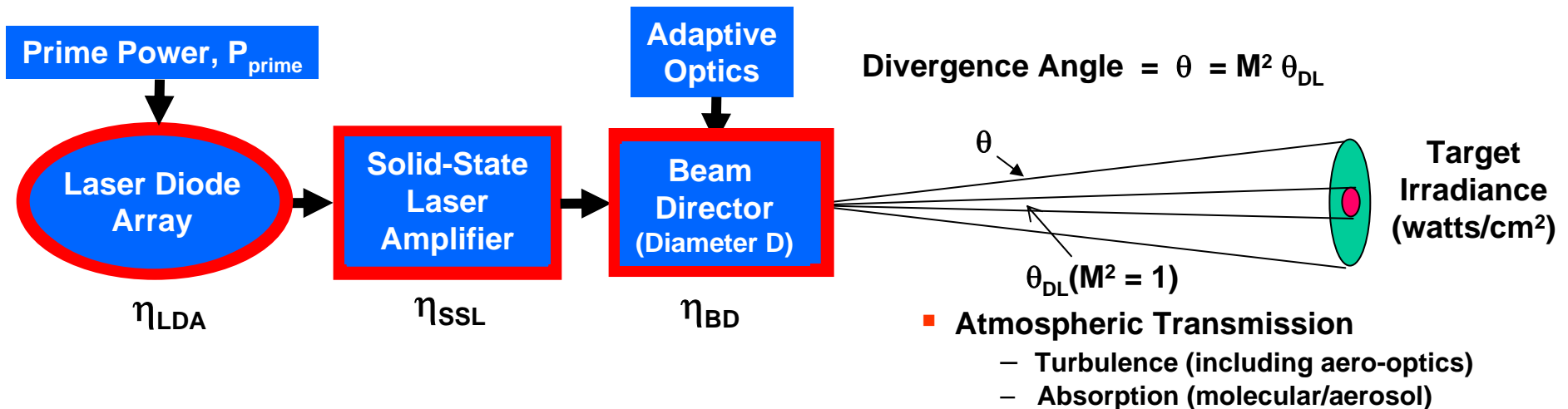
- Efficient
- All-Electronic Steering
- Scalable to High Power and Aperture Size
- Conformal to Platform
- Minimum Size/Weight

■ Program

- APPLE

■ Technologies

- Conformal Phased Array
- Risley Prisms
- Gimbaled



■ Power Delivery Efficiency $\sim \frac{\eta_{\text{LDA}} \eta_{\text{SSL}} \eta_{\text{BD}}}{M^4}$

Challenges

- Power
- Efficiency
- Beam Quality
- Size and Weight
- Lifetime/Reliability
- Electronically-steered, Conformal Optical Phased Arrays with AO

Beam Directors - Applications

Programs

- APPLE
- COCHISE
- AD

Agenda:

- APPLE Beam Directors
- COCHISE Coherent Diode Arrays
- Coherent Diode Arrays integrated with APPLE
- Challenges

ers